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THE STRESS-CORROSION CRACKING OF STEELS
IN AMMONIA -- A SURVEY --
WITH CONSIDERATION GIVEN TO OTEC DESIGN

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SOLAR ENERGY

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March 1980

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EXECUTIVE SUMMARY

Carbon steel, alloy steel, and high-strength, quenched and tempered steel under applied or residual stress and especially when cold formed and/or welded without subsequent thermal stress relief are subject to failure by stress-corrosion cracking (SCC) in air-contaminated dry ammonia.

Contaminants in ammonia that are responsible for SCC are air (oxygen) and combinations of oxygen and nitrogen. Neither nitrogen nor carbon dioxide alone or combined contribute to this type of failure.

Water (distilled, deionized, or steam condensate) has been shown to be an effective inhibitor of SCC of steel when present in the amount of 0.08 to 0.5% by weight (800 to 5000 ppm). A minimum of 0.2% (wt) water is recommended by the U. S. Department of Transportation (DOT). In experimental investigations, hydrazine (N_2H_4) has also been shown to be an effective SCC inhibitor at weight concentrations similar to water. Commercial use of hydrazine to protect steel ammonia tanks, pipelines, etc. has not evolved since water is less costly to use.

Although the protection of simple steel structures, such as tanks, from SCC in ammonia has been adequately demonstrated, the Ocean Thermal Energy Conversion (OTEC) system is more complex in that in at least one design, the shell-and-tube heat exchanger, large areas of dissimilar metal couples will be exposed to ammonia. In such a system, galvanic corrosion is likely to occur. Also, large areas of cathodic metal, such as titanium, stainless alloy or copper-nickel coupled to steel may accelerate the SCC process in ammonia to the detriment of steel, even in the presence of 0.2% (wt) water.

Research is needed to better define these areas of criticality.

Organizations with regulations on materials usage in handling ammonia have been detailed. DOT, Code of Federal Regulations-49-Transportation states: "No aluminum, copper, silver, zinc or alloy of any of these metals shall be used in cargo tank construction." Brazing alloys containing copper and silver would appear to be included. Guidelines for OTEC construction appear to be warranted.

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ABSTRACT

Carbon steel, alloy steel, and high-strength, quenched and tempered steel, when under applied or residual stress and especially when cold formed and/or welded without subsequent thermal stress relief, are subject to failure by stress-corrosion cracking (SCC) in air-contaminated dry ammonia.

Water as well as hydrazine when present in small amounts have been shown to be effective inhibitors in an all steel system.

Galvanic corrosion between dissimilar metals and/or accelerated failure by SCC of stressed steel as a result of galvanic coupling may be of concern.

Where water has proven effective as an inhibitor of SCC in an all steel system, it may not be adequate in a mixed metal system.

With aluminum tubes, the tube sheet will either have to be solid aluminum, aluminum clad steel or some nonconductive coating will be necessary to effectively remove the cathodic alloy from the galvanic circuit.

Research is required to determine the severity of the coupling effect between dissimilar alloys in ammonia under OTEC conditions; especially the possibility of accelerated SCC failures of stressed steel where the presence of an inhibitor in the ammonia may not be sufficient to override the galvanic coupling effect.

I. INTRODUCTION

A number of factors are known to influence the stress-corrosion cracking (SCC) susceptibility of steel in ammonia. These include the composition of the alloy, its metallurgical structure, heat treatment, stress level, anode-to-cathode area relationship (e.g., interstitial and galvanic coupling effects), welding practices, environmental conditions, temperature, the presence or absence of inhibitors and, finally, the manner in which specimens are prepared for test, tested, and results assessed. Of these, the combination of an applied and/or residual stress and a corrosive environment are chiefly responsible for SCC.

Various grades of steel have been in ammonia service for over fifty years. During the early years, beginning in the 1920's, low-strength carbon steels were found to be adequate for liquid ammonia manufacture and storage. Reciprocating compressors were used and, undoubtedly, the ammonia, which in itself was not of extraordinarily high purity, was contaminated with both oil and water. Since most ammonia was used at the point of manufacture, there was little need for over-the-road transport. Therefore, the need to construct light-weight tanks of higher strength steel suitable for road transportation did not exist.

The SCC of carbon and alloy steels in ammonia service has occurred spasmodically, worldwide, since about 1950. Countries where tank failures have been noted include South Africa, Finland, Denmark,¹ Ireland, England, and the United States,² among others.

During the 1950-1960 period, there was an increase in the use of anhydrous ammonia for agricultural purposes. This led to a demand for more tanks for storage, over-the-road transport, and for application purposes. Light-weight, high-strength steels were developed in order to maximize truck-hauling efficiency and minimize transport weight. Thus, increasing quantities of both low-strength carbon steel and higher strength, quenched and tempered steel appeared in reactors, storage tanks, agricultural nurse tanks and applicator tanks, as well as in pipelines and over-the-road tanks on trucks. As time progressed, more frequent SCC failures of steel in ammonia service were noted. Collectively, it can be stated that although some tank failures were observed in the early years, the problems associated with SCC were relatively few before 1956. From 1956 to 1960, approximately 3% of the containers in ammonia service were failing after three years of service. Failures occurred on the interior surfaces of tanks, principally on the heads adjacent to the shell-to-head weld area. Investigators found that although the tanks which failed had been built to the American Society of Mechanical Engineers (ASME) code, they had not been thermally stress-relieved after welding. These failures brought forth a large industrial and scientific effort on a worldwide scale aimed at inspecting existing tanks, determining the cause of failure, and assessing what action might be undertaken to solve the problem. At this time, a number of technical associations became interested in the SCC problem, and task groups were formed to participate in the investigations. The associations that have an interest in this field are listed in the Appendix. As a result of these actions, it was agreed that three areas would be investigated in order to determine how best to control the propensity for stressed steel to crack in ammonia. These three areas were: (a) ammonia, (b) steel, and (c) environmental factors.

II. AMMONIA*

A. Purity**

The purity of ammonia depends on the grade. During the early years of manufacture only one grade was required and, although considered "pure," it contained water as well as oil. The presence of oil was due to the lubricants used in the compressors. During the 1920-1930 period it was often found that the interior surface of ammonia storage tanks was filmed with oil. Quite likely, the oil film was beneficial in lessening the susceptibility of stressed steel toward SCC. However, it should also be recognized that at that time water was also present as a contaminant which, although not recognized as such, was beneficial as an inhibitor of SCC. Also, low-strength carbon steels were used in tank fabrication and, therefore, stresses were not of a high order.

With the introduction of controlled atmosphere annealing for metallurgical processing, a market was developed for a higher purity metallurgical-grade ammonia. Also, about this same time there was a need for refrigeration-grade ammonia, which was more pure than the commercial grade. Agricultural-grade ammonia is commercial-grade ammonia with approximately 0.2% (wt) water added for imparting resistance to SCC. Specifications have been developed for each grade and these are presented below.

1. *Metallurgical Grade*[†]

The purity of this grade of ammonia is 99.995% (min). Water content is 33 ppm (max) and oil 2 ppm (max).³ A typical analysis is as follows: water, 18 ppm; oil, 0.9 ppm; noncondensable gases, 35 ppm (volume); iron carbonyl, 0.8 ppm; chloride, 0.12 ppm; and hydrogen sulfide, not determined. It should be noted that this grade of ammonia is not sufficiently pure to avoid the possibility of SCC of stressed steel in the absence of water (inhibitor).

* Ammonia is priced according to grade and point of shipment. The agricultural grade is the least costly and the price increases with purity. The price of ammonia is the least at the point of origin. One plant located in Texas advised that ammonia purchased on the West Coast might be 65% more expensive than when purchased in the Gulf Coast area.

**In a number of laboratory tests conducted on various grades of steel after 1956, not all sources of ammonia gas caused SCC, but 50-70% did. This suggests that the method of ammonia manufacture may play a part in SCC, i.e., that air, which includes oxygen and other "inert" gases, may contaminate the ammonia during its manufacture. It can be added that the manner in which ammonia is loaded into tanks and the tanks purged are both important considerations.

[†] Steels used for handling this grade of ammonia requires a mandatory postweld thermal stress relief and exclusive use of lower strength nonquenched and tempered (NQT) steel.

2. Refrigeration Grade* (Also called "R" grade)

The ammonia content is guaranteed to be not less than 99.98% when determined as the difference between 100% and total residue. Water present, 0.015% (max); [Allied Chemical Company: water less than 0.01 ml per 100 ml of ammonia]; oil, 3 ppm (max); and 0.2 ml/gm noncondensibles (max).² No residue in excess of one part in 6000 by weight should be found on evaporation at atmospheric pressure and no pyridine should be present.

3. Commercial Grade (Also called "C" grade)

The ammonia content should not be less than 99.5%.

4. Agricultural Grade (Fertilizer Grade)

Agricultural ammonia is commercial-grade ammonia (99.5% NH_3) to which water has been added for the inhibition of SCC of steel. Nominally, the water content is 0.2% (wt)(min). However, in one instance it was found that a manufacturer called for 0.5% (wt)(max) water without a minimum being specified. This same manufacturer limited the presence of oil to 5 ppm (max). A second manufacturer claimed they used 0.1-0.25% (wt) water as an inhibitor.⁴

B. Contaminants

The contaminants in ammonia that were found to cause SCC of steel were (a) air, (b) oxygen, and (c) oxygen and nitrogen combined.^{5,6} It has also been determined that neither carbon dioxide nor nitrogen will cause SCC of steel. Early investigative work attributed some SCC failures to the presence of carbon dioxide in ammonia, but this was later proved incorrect.⁵ Nitrogen in combination with oxygen is not as damaging as oxygen alone, but takes a close second place. Other contaminants that were investigated include compressor oil (1%), ethyl mercaptan (0.005%), sodium cyanide (0.01%), sodium chloride (1.0%), and copper sulfate (0.1%). In the absence of air and water (refrigeration-grade ammonia), one specimen of four failed while the effect of compressor oil and sodium cyanide were being investigated and two of four failed in the presence of copper sulfate. With the same grade of ammonia and in the presence of air (oxygen) but no water, one specimen of four failed in sodium cyanide and copper sulfate. Again, in the same grade of ammonia and in the presence of air and 0.5% (wt) water, none of the four specimens failed in each contaminant. All of the foregoing results were obtained with T-1** steel (high strength) and AISI† 4130 alloy steel tuning-fork specimens (Figure 1) in the cold-worked, welded, and stressed condition. Test duration was 115 weeks. It should be appreciated that this represents a very severe test for SCC susceptibility and illustrates the tremendous

* Steels used for handling this grade of ammonia requires a mandatory postweld thermal stress relief and exclusive use of lower strength nonquenched and tempered (NQT) steel.

**Trademark. United States Steel Corporation, Pittsburgh, PA.

† American Iron and Steel Institute.

Figure 1

Tuning-fork Specimens Used in Stress-corrosion Studies.
Approximately actual size. (From Loginow and Phelps)

advantage of having water present as an inhibitor. Other tests on these steels included refrigeration-grade ammonia in the presence of air with water additions of 0.5, 1.0, 2.0, and 4.0% (wt). No failures occurred at any of these water concentrations.

Typically, other contaminants might include inert gases such as helium and argon at 0.5 cc/gm (max). Helium is found in the natural gas from which ammonia is manufactured, whereas argon occurs from the air. Normally, in the manufacturing operation, these gases are vented from the converters when they reach a concentration of about 1.5%. Higher inert-gas concentration adversely affects the conversion of synthesis gas to ammonia.

One ammonia manufacturer also stated that quite often chloride is found in ammonia to a level of about 20 ppm. Another claimed that "typically" anhydrous ammonia contained 20 to 30 ppm chloride.⁴

C. Inhibitors*

As described above, water has been shown to be an effective inhibitor of the SCC susceptibility of stressed steel in air (oxygen)-contaminated ammonia. The beneficial effects of the presence of water have been demonstrated under field conditions as well as in laboratory experiments involving the use of tuning-fork specimens and in the more recently used slow-strain rate test.⁷⁻¹⁰ The effective range of water as an inhibitor of SCC of steel in air-contaminated ammonia appears to be from 0.08 to 0.5% by weight.

Hydrazine** has also been found to serve as an effective inhibitor, its concentration being on the same order as water. It is believed that hydrazine (N_2H_4) acts to scavenge oxygen, thereby removing it from the system, i.e.,

The equation suggests the possibility of a dual function, removing oxygen and, interestingly, supplying water to the system. To this writer's knowledge, hydrazine has not been used in ammonia service on a commercial basis simply because water has been less costly. However, the value of hydrazine

* Designers of OTEC systems are concerned with the effect of water in ammonia on heat transfer. Limiting or removing water to improve heat transfer could be in conflict with the need for water to inhibit the SCC of steel. Evaporated ammonia cannot be expected to contain sufficient water to inhibit the SCC of steel. Water addition to the vapor would probably require periodic removal to limit its concentration, thus, a loss of heat-transfer efficiency. Therefore, it appears that either some sacrifice in heat-transfer efficiency with the presence of water will have to be tolerated or one must identify a steel of certain composition or condition so that water is not required for SCC inhibition.

**Hydrazine -- a colorless liquid, solidifies at 1.8 to 2.0°C (35°F) and boils at 114.5°C (238°F). Hydrazine solutions and vapors are toxic and inflammable when mixed with air. [Encyclopaedia Britannica, Vol. 11, 930 (1968)].

in preventing the SCC of steel in air-contaminated ammonia has been demonstrated a number of times in laboratory tests. United States Steel Corporation^{6,11} has done work on the beneficial effect of hydrazine and has found 0.2% (wt) hydrazine as effective as water in mitigating SCC in both ammonia liquid and vapor. Other inhibitors were also investigated and are discussed in the report.⁶

III. STEEL

Numerous steels have been investigated for failure by SCC in ammonia in the field and in laboratory tests using tuning-fork specimens and the previously mentioned slow strain-rate test. Steels that have been found to fail in air-contaminated ammonia are as follows:

Carbon Steel (Stressed)	A 517 Grade F
A 202B (Base metal and heat-affected zone)	A 285
A 212	Spring Steel (High in carbon)
ASME Case 1056 Steel	Line Pipe Steel API x 42*
A 204B	Line Pipe Steel API x 46*
4130	Line Pipe Steel API x 52*
4140	Line Pipe Steel API x 60*
A 515 Grade 70	9% Nickel Steel ⁷
Si-Mn-Al Fine Grain (Denmark)	403 Stainless Steel (Rivets - soft condition)
T-1 (U. S. Steel Corporation)	

(Water was not present under these service or test conditions.)

Typical SCC failures in the various grades of steel are shown in Figures 2 through 9.

A. Strength

Laboratory investigations on a number of these steels showed that the most severe SCC occurred with steels in the cold-worked, welded and stressed condition, in which the steel is at a very high stress level and a heat-affected zone is present. The next most severe condition was the cold-worked and stressed condition, whereas the least severe was the stressed-only condition. The severity of cracking generally decreased with stress level reduction with nonspring steels. It is apparent from all of this work that there is a distinct advantage in using steel with the lowest strength possible consistent with engineering design and economic requirements.

B. Composition

Investigative work on the effect of composition of steel on SCC susceptibility in air-contaminated ammonia has not been extensive. Copper in steel was found to be innocuous at low concentration levels. Nickel steel (9% Ni) suffered SCC.¹² The effect of other elements on SCC, such as Cr, Mo, etc., have not been reported in the literature.

*Welded and thermally stress relieved.

50 μ m

Figure 2

Crack in ASTM A 517 Steel Tank after Anhydrous Ammonia Service. Etched in nital. (From Loginow)

External welds

25 mm

Figure 3

Cracking in the Head of an Ammonia Tank Opposite an External Doubler Plate Revealed by the Wet Fluorescent Magnetic Particle Method. The cracks are located both between and outside parallel external welds. (From Loginow)

Figure 4

Cross Section of ASTM A 517 Steel Tank Head That Cracked in Anhydrous Ammonia Service. Not etched. (From Loginow)

100 μm

Figure 5

Cracks in A 517 Steel Tank after Anhydrous Ammonia Service. Etched in nital. (From Loginow)

50 μm

Figure 6

Cross Section of a Cold-formed ASTM A 515 Grade 70 Steel Tank Head That Cracked in Anhydrous Ammonia Service. Etched in nital. (From Loginow)

100 μm

Figure 7

Stress-corrosion Cracks in Heat-affected Zone of ASTM A 202 Steel Caused by Anhydrous Ammonia. Etched in picral. (From Loginow)

50 μm

Figure 8

SEM Fractograph of an Ammonia Stress-corrosion Crack in Heat-affected Zone of ASTM A 517 Steel. (From Loginow)

5 μm

Figure 9

SEM Fractograph of a Stress-corrosion Crack in AISI 4130 Steel. (From Loginow)

10 μm

→
Crack Propagation

C. Metallurgical Factors

Fine-grain steels appear to offer an advantage over coarse-grain steels in resisting SCC in air-contaminated ammonia.

D. Heat Treatment

Where the size of the vessel will permit, a full anneal is desirable, particularly if cold-formed heads have been used in conjunction with welded construction. The use of hot-formed heads is preferred, and the welds can be stress relieved locally after fabrication. If 0.2% (wt) water (min) is present in the ammonia as an inhibitor, tanks can be constructed with hot-formed heads with no stress relief after welding. This applies to carbon steel construction. Higher strength quenched and tempered steels with hot-formed heads should be stress relieved after welding, and water at 0.2% by weight (min) must be present as an inhibitor. Designers of steel vessels for OTEC systems should take into account the effect of thermal stress relief on the levels of strength that can be counted on.

E. Welding

Recommended welding practices for each grade of steel used should be followed.¹³ Welding should be kept to a minimum. External tank welds for the attachment of various items should be treated the same as internal welds, as SCC failures can occur at heat-affected zones.¹⁴

The beneficial effect of a postweld heat treatment in an A 517 steel is shown in Figure 10. Note the tremendous reduction in hardness following the heat treatment--such treatments also significantly reduce the level of residual stress.

IV. ENVIRONMENTAL FACTORS

A. Temperature

Warm temperatures appear to increase the SCC susceptibility of steel in air-contaminated ammonia, whereas cold temperatures are beneficial in reducing SCC failures. Care, however, should be taken in the selection of the steel to be used in cold conditions to avoid the possibility of brittle failure.

B. Dew Points

Stressed steel in air-contaminated ammonia vapor, even with 0.2% (wt) water present in the liquid ammonia, is more likely to fail by SCC under condensing conditions, i.e., when the steel is cooler than the liquid, than when the steel is warmer than the liquid. This is best illustrated in an article by Ludwigsen and Arup.¹⁵ They assume a large pressurized storage tank half filled with ammonia, as shown in Figure 11. Assuming the ammonia contains sufficient oxygen to cause SCC with no water present, the composition

Figure 10

Typical Hardness Traverses in Weldments of ASTM A 517 Steel. (From Loginow)

Figure 11

A. 5000 m³ Steel Sphere for Liquid Ammonia. The tank is shown half filled with liquid ammonia at 17 C where the saturated vapors exert a pressure of 8 kg/cm² above the atmospheric pressure. (From Ludwigsen and Arup)

of the ammonia liquid and vapor would be as shown in Table I.* Quoting this article, "the distribution coefficients of these constituents between liquid and vapor are not very well known, but if we assume one likely set of conditions, the corresponding composition of the vapor would be that given in the second column in Table I. It is seen that the vapor contains 600 times more oxygen and only one third of the water as compared with the liquid."

"At uniform temperature, the top inner surface of the tank will be wetted by a thin (10 to 100 molecular layers) film of adsorbed liquid ammonia, and under equilibrium conditions this should be of the same composition as the bulk liquid."

"In reality, the temperature of the tank top will vary considerably between day and night, and in consequence the tank top will shift between being dry and wet. During a cold night, copious condensation will occur, liquid ammonia will run down the walls, and the composition of this liquid has no time to reach equilibrium, but its composition shifts toward the composition of the vapor. It can safely be argued that it will always contain more oxygen and less water than the bulk liquid, and therefore, be more likely to promote SCC."

Considering that effective inhibition to SCC of stressed steel in air-contaminated ammonia has been achieved with 0.08 to 0.5% (wt) water and this represents 800 and 5000 ppm, respectively, it will be noted, in referring to Table I, that insufficient water is present in the vapor to prevent SCC.

V. OTHER FACTORS TO CONSIDER IN OTEC DESIGN

So far we have discussed rather simple systems, a relatively large area of steel as represented by the tank, and minor amounts of more cathodic metals, such as stainless steel valves or valve trim, that might be coupled to the tank. In such a situation, the large area of steel predominates and the presence of the cathodic metal is hardly noted from a galvanic standpoint.

OTEC design is much more complex. Heat-exchanger tube and flat plate surface area (in flat plate heat exchangers) should equal or exceed the steel shell surface area and, thus, exert considerable galvanic effect where surfaces are flooded with liquid ammonia, such as in shell-and-tube heat-exchanger evaporators. With shell-and-tube condensers, galvanic effects should be most noticeable on the ammonia side between the steel tube sheet, should bare steel be used, and the alloy tubes. The thin film of ammonia present would limit the attack to the tube-tube sheet junction area or at points where dissimilar metals contact each other, such as between tubes and their support members (baffles).

An electrochemical galvanic series for metals in ammonia has been established in uncontaminated liquid ammonia and air-contaminated liquid ammonia, as shown in Figures 12 and 13.¹⁶ In uncontaminated liquid ammonia,

*The distribution of water and oxygen between ammonia liquid and vapor shown in Table I apparently did not involve the application of heat to vaporize the ammonia, as would be the case with OTEC.

Note--The distribution or partition coefficients between liquid and vapor have not been completely defined for water and ammonia.

TABLE I. Distribution of Oxygen and Water between Liquid and Vapor in Ammonia Storage. The total amounts have been calculated for the tank shown in Figure 11.

	Composition		Total Amounts	
	Liquid (ppm)	Vapor (ppm)	1500 Tons Liquid (kg)	15 Tons Vapor (kg)
Oxygen	10	6000	15	90
Water	2000	600	3000	9

From Ludwigsen and Arup.¹⁵

Figure 12

Galvanic Series in Uncontaminated Liquid Ammonia. (From Jones and Wilde)

Figure 13

Galvanic Series in Air-contaminated Liquid Ammonia. (From Jones and Wilde)

carbon steel is shown to be anodic to the stainless steels and titanium (Figure 12). In air-contaminated liquid ammonia, aluminum is shown to be anodic to titanium, the stainless steels, and carbon steel. Since on occasion OTEC ammonia tanks will be subject to air during filling and draining, initially and during inspection and maintenance periods, these potential differences are of interest. Of more importance is the anodic condition of steel in relation to titanium, stainless steel, and, although not shown, probably copper-nickel, as shown in Figure 12. This galvanic effect may be an accelerating factor as regards the SCC susceptibility of steel and should be investigated further.

In some OTEC designs, titanium and stainless alloy tube surfaces on the ammonia side are to be coated with an aluminum oxide coating* for surface enhancement. This coating may serve another advantage -- that of removing the noble (to steel) titanium and stainless surfaces from the system. Also, in the case of copper-nickel tubes, a bi-metal tube is being considered that will place steel on the ammonia side and copper-nickel on the seawater side, to the advantage of both systems.

Galvanic effects in ammonia may be important where bare aluminum tubes are being considered. Under conditions where bare aluminum tubes are in contact with a steel tube sheet on the ammonia side, there is a good chance that accelerated attack due to the galvanic coupling effect will occur to the detriment of the aluminum. With bare aluminum tubes, it may be necessary to aluminum clad the backside (ammonia side) of the tube sheet to minimize galvanic problems between the tube and tube sheet. Solid aluminum tube sheets might also be used or a protective coating (resistant to ammonia) could be applied to the surface of the steel, thereby minimizing its cathodic effect.

VI. GENERAL CORROSION RESISTANCE OF POTENTIAL OTEC ALLOYS TO AMMONIA

The specific material to be used for an intended purpose in a corrodant has not been defined by Engineering Society codes.¹⁷ Carbon and low alloy steels are quite generally used in handling ammonia.

High corrosion rates can be expected of copper and amorphous metals such as zinc, aluminum, lead, and tin when they come into contact with caustic solutions such as ammonium hydroxide. Aluminum should not be used even in mildly alkaline solutions.¹⁸

When in contact with copper, ammonium hydroxide forms the complex copper-ammonium ion $[\text{Cu}(\text{NH}_3)_4^{++}]$ and causes rapid corrosion of the copper. The same effect occurs with the amphoteric metals.

Although the copper-nickels are likely to suffer general corrosion in ammonia, more so with 90/10 Cu-Ni (CA** 706) than with 70/30 Cu-Ni (CA 715), both alloys should be resistant to SCC. There is no known instance of SCC

* "High Flux" coating. Trademark. Union Carbide Corporation, Linde Division, Tonawanda, New York 14150.

**Copper Alloy. Designation developed by The Copper Development Association.

of CA 706 in modern day ammonia service. It is recognized, however, that the alloys must have solutionized iron in their structure to resist SCC under stressed conditions.^{18,19} Earlier reports of the SCC of CA 706 have been attributed to the lack of iron in the alloy. (CA 706 specification: 1.0 to 1.8% Fe.) The United States Coast Guard (USCG) regulations for "Handling Hazardous Materials in Barges," 46 CFR 151.50-32 (Anhydrous Ammonia)²⁰ does not permit the use of copper, copper alloys, copper-bearing alloys, aluminum, cast iron or brazed joints for handling ammonia. The regulation applies to tanks, pipe, valves, flanges, etc. This regulation is also observed by The Office of Merchant Marine Safety Cargo and Handling (Hazardous Branch).

Department of Transportation (DOT) regulations (Code of Federal Regulations-49-Transportation, 173.315, (p. 411) Specification Containers, DOT-51, MC 330 and MC 331²¹ states: "No aluminum, copper, silver, zinc or alloy of any of these metals shall be used in the cargo tank construction where it can come into contact with the lading (ammonia)". [Authors' comment: this would include brazing alloys that normally contain copper and silver.]

A number of alloys have been exposed to metallurgical-grade ammonia for one and eight months. Results are given in Table II. From this it will be noted that all metals listed, except zinc, were satisfactorily resistant to general corrosion. It should be recognized, however, that this grade of ammonia has a maximum water content of 33 ppm, whereas, OTEC ammonia will probably contain 2000 ppm, minimum. Thus, it would be expected that slight differences in general corrosion from those shown would be expected to occur.

From the data (Table II), aluminum appears to warrant further investigation since the initial corrosion rate was quite high. Also, Jones and Wilde¹⁶ have shown aluminum to be anodic to steel in ammonia.

Various grades of aluminum (3003, 5052, and 5086) have been subjected to laboratory testing in mixed ammonia/seawater environments simulating several possible OTEC shell-and-tube heat-exchanger conditions.²² In one study, seawater at several different rates was permitted to slowly leak into ammonia, whereas in another ammonia at several different rates was permitted to leak into seawater. All of the aforementioned aluminum alloys as well as pure (CP) titanium were exposed in each environment. Corrosion was found to be minimal on the aluminum alloys except for pitting on 3003, 5052, and 5086 at 8 ppm leakage of ammonia into 30°C (86°F) seawater and on 5052 at 8 ppm ammonia and 5°C (41°F) seawater. High leakage rates of ammonia (exceeding 30 ppm) into warm 30°C (86°F) seawater would most likely lead to tube-scaling problems that could drastically reduce heat-transfer capability and interfere with mechanical cleaning by the Amertap* or M.A.N.** systems.

*Trademark. A rubber-ball-type tube cleaning system manufactured by the Amertap Corporation, Box 151 T, Mineola, New York 11501.

**Trademark. A brush and cage tube cleaning system manufactured by Maschinenfabrik Augsburg-Nürnberg, Aktiengesellschaft, Munich, Germany. American representatives -- American Tube Cleaning Systems, Inc., 1114 Avenue of the Americas, New York 10036 and Water Services of America, Inc., Milwaukee, Wisconsin.

TABLE II. General Corrosion Performance of Various Materials in Liquid Ammonia

Alloy Designation	Weight Change (mg/dm ²)	
	1-month Exposure	8-month Exposure
Type 304 SS	0	+3.0
Type 316 SS	0	+3.4
Type 430 SS	0	+3.8
Type 410 SS	-7.52	+0.75
Al-3003	+7.52	+1.9
Al-5454	+12.8	+1.12
Titanium	0	+3.0
Monel	-1.5	-3.4
Inconel 600	-1.5	+2.6
Zinc	-47.0	-21.0
Iron	-2.25	-1.5
Carbon Steel	-3.76	-0.75
Hastelloy C	-1.13	+0.75
ASTM 517 Grade F Steel	-3.0	-0.75

Note: + means weight gain, and - means weight loss. From Jones and Wilde.¹⁶

Titanium (CP), exposed under similar conditions of test, was shown to be completely resistant to corrosion and pitting. Scale formation was also more easily removed. Titanium (Grade 4) has been found to be completely resistant to SCC in the presence of ammonia, with and without water and seawater present.²³

Ductile iron has been used for valves in ammonia plants. Forged steel has also been used but is considered more expensive as a valve material than ductile iron. Cast iron is not used for valves and does not seem warranted for other applications due to safety and health hazards associated with handling ammonia.

VII. STRESS-CORROSION CRACKING MECHANISM OF STEEL IN AMMONIA

Jones, et al.²⁴ studied the electrochemical polarization characteristics of ASTM A 517 Grade F constructional alloy steel in liquid anhydrous ammonia and found that it forms a passive film in ammonia contaminated with oxygen, as evidenced by a noble electrochemical potential. The steel formed a more active (negative) potential. Nitrogen was found to be inactive electrochemically. The SCC of steel in liquid ammonia features galvanic action between active emergent slip steps at the head of the crack and the surrounding passive surface behind and encompassing the crack path.

Deegan and Wilde²⁵ have shown that SCC is not due to hydrogen embrittlement.

VIII. TURBINES AND COMPRESSORS

There are several opinions regarding the quality of ammonia transported through the turbine or compressor. The temperature of the ammonia should be low, since the maximum temperature on evaporation should not exceed 32°C (90°F), which is the expected maximum ambient temperature of surface seawater entering the evaporator at likely UTEC sites. Some droplets are likely to be present in the ammonia vapor, thus, impingement and erosion may be a problem, particularly on turbine blades.

These droplets may contain some water and chlorides, the latter from that normally expected to be found in ammonia (about 20 ppm) as well as from seawater seepage into the evaporator. Several opinions exist regarding the presence of water in the ammonia vapor. Some feel that the amount present will not be sufficient to arrest the SCC susceptibility of stressed steel where exposed downstream from the evaporator discharge, while others feel that there will be a sufficient amount of water present to prevent the SCC of steel. It is quite obvious that should steel be used in the turbine, such as for the rotor where a Ni-Cr-Mo-V steel has been proposed, some form of inhibitor should be present to arrest the possibility of SCC. If there is sufficient water present, which is highly questionable, fine; if not, then some other inhibitor, such as hydrazine* or combinations of inhibitors will be required, using those that are likely to have a vapor pressure close

*The presence of a substantial amount of oxygen (air) may require an excessively high level of hydrazine, which would probably preclude consideration because of cost.

to that of ammonia. Other routes to follow are (a) maintain air (oxygen) at an extremely low level, as close to zero as possible, and minimize its introduction by operating at higher than atmospheric pressure and (b) use alloys not likely to corrode in the environment, or to be susceptible to SCC.

Types 403 and 410 stainless steel have been suggested, but there is some concern²⁶ that these grades of stainless steel will not be adequate and are likely to fail by SCC. Other alloy suggestions have been made, such as austenitic stainless alloys or, should higher strength than the 18/8 Cr-Ni stainless alloys be desired, the precipitation-hardening grades of stainless steel. Titanium has also been suggested as a suitable turbine-blade material. If the ammonia is dry, there is a good chance that aluminum will be adequate, but the resistance of higher strength aluminum alloys will have to be determined in the expected environment. Obviously, some research is required in this area because negligible information is available in the literature on suitable alloys or on the partition reaction between water and ammonia when ammonia is flashed to a vapor.^{15,27}

Failures have been noted in turbines and compressors in ammonia synthesis plants.²⁸ In a recent survey (1977-1978), primary reforming and major compressors and turbines were the leading contributors of major equipment downtime, accounting for 63% of the downtime and 3-1/2% of the shutdowns/year during the last four survey years of the American Institute of Chemical Engineers (AIChE). The synthesis gas compressor leads the list and has the highest percentage (25%) of the major equipment downtime attributed to a single major equipment item. The average ammonia plant had one shutdown due to the "syn-gas" compressor every 14 months during the 1971-72 survey period, once every 12 months during the 1973-74 period, and once every 9-1/2 months during the 1975-76 period. Downtime days per shutdown averaged about four. "Syn-gas" compressor problems are widespread, two thirds of the plants had at least one shutdown during the 1975-76 period, with one plant reporting ten shutdowns over the two-year period.

Some of the reasons for failure were as follows: (a) severe vibrations on compressor and/or turbine, (b) rotor failed, (c) compressor thrust collar broke, (d) coupling bolts failed, (e) compressor seal failed, (f) broken blades on turbine, (g) reduction gear bearing failed, and (h) compressor "O"-ring failed, etc.

IX. RESEARCH NEEDS

A. Study the effect of galvanically coupled dissimilar metals in both liquid and gaseous (condensing) ammonia with and without inhibitors and chlorides present.

1. Metals should include titanium, Grade 2, coupled to steel; CA 706, CA 722, and CA 715 copper-nickel coupled to steel; Alclad aluminum and bare 5052 aluminum coupled to steel; and "20-24-6" stainless alloy coupled to steel. Area ratios between dissimilar metals should be varied.

2. Similar tests should be conducted where the steel is with and without welds and stress.

B. Assess the suitability and SCC resistance of new low-to-moderate strength commercial grades of steel to possible OTEC ammonia conditions in the absence of inhibitors.

C. Study the effect of temperature on the SCC susceptibility of steel in ammonia.

D. Determine the possible beneficial effect of an Al_2O_3 coating (Linde Division process) on cathodic metals, such as titanium and stainless alloys, in reducing their expected detrimental galvanic effect on steel in ammonia, with and without inhibitors present.

E. Determine the effectiveness of low quantities (less than 0.1%) of water in ammonia (liquid and vapor) and relate its need and effectiveness to oxygen content with and without the presence of varying quantities of hydrazine as an SCC inhibitor of fabricated steel.

F. Determine the partition (distribution) coefficients between liquid and vapor for water and ammonia and hydrazine and ammonia and hydrazine-water and ammonia. Various levels of oxygen should be included in the program.

G. Study the effect of "forced" evaporation on the distribution coefficients of water and ammonia, including specific tests as required for OTEC conditions. Referring to Ludwigsen and Arup¹⁵ and Table I, apparently the distribution of water and oxygen between ammonia liquid and vapor did not involve the application of heat to vaporize the ammonia.

H. Develop an inhibitor that will carry through the turbine and be effective in small amounts in all components of the OTEC cycle, both with and without the presence of water. (Can water and hydrazine be used jointly to avoid the need for postweld heat treatments?)

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APPENDIX

A. Associations and Specifying Organizations Dealing with Ammonia

1. Compressed Gas Association

500 Fifth Avenue, New York, New York 10036

Bulletins:

TB-2 Guidelines for Inspection and Repair of MC-330 and MC-331
Cargo Tanks
G-2 Anhydrous Ammonia
G-2.1 American National Standard Safety Requirements for the Storage
and Handling of Anhydrous Ammonia, K 61.1
G-2.2T Tentative Standard Method for Determining Minimum of 0.2%
Water in Anhydrous Ammonia

2. The Fertilizer Institute

1015 18th Street, N.W., Washington, DC 20036. Telephone: (202)
466-2700

Mr. Karl T. Johnson, Vice President, Member Services
Mr. James Massis, Director of Safety Programs

(Formerly, Agricultural Ammonia Institute Combined with The National
Plant Food Institute; Agricultural Ammonia Institute; and Agricultural
Nitrogen Institute)

Document:

"Safety Requirements for Storage and Handling of Anhydrous Ammonia"

Report:

"Stress Corrosion Cracking of Steel in Agricultural Ammonia." A
report from The Research Committee of the Agricultural Ammonia Institute.¹¹

Additional Information:

The Fertilizer Institute has a device for low-level NH₃ gas sensing.
(U. S. Steel Corporation, Research Laboratory, Monroeville, PA has also
developed a sensing device for determining low levels of ammonia.)

A \$1 million study on ammonia spills has been undertaken by
A. D. Little, which is jointly funded by The Fertilizer Institute, the USCG,
and ANSI. Tests have been conducted at the Naval Weapons Center, China
Lake, CA.

Worked jointly with NACE Committee T5E-10 (1971-1972) to establish
guidelines for ammonia containers. The preliminary working group of this
Committee made the following suggestions after a 1956 study. (Note: This
is an early document issued in 1961. Generally, one should follow DOT
recommendations.)

(a) "Tanks for ammonia service should have (1) hot-formed heads, (2) thermally stress-relieved cold-formed heads, or (3) full thermal stress-relief of the entire tank following fabrication.

(b) "Tanks over 36 inches in diameter should be either fully thermally stress relieved or fabricated with heads that are hot-formed or thermally stress relieved. Service experience has indicated that ammonia applicator tanks with a diameter less than 36 inches are relatively insensitive to cracking.

(c) "Extreme care should be taken to eliminate air from agricultural ammonia systems.

(d) "Agricultural ammonia should contain water [distilled, deionized, or steam condensate] to inhibit SCC; minimum water at 0.2% (wt)."

3. International Institute of Ammonia Refrigeration

Chicago, Illinois

Brochure:

"Equipment Design and Installation of Ammonia Mechanical Refrigeration Systems"

4. American National Standards Institute, Incorporated (ANSI)

1430 Broadway (between 39th and 40th Streets), New York, New York 10018

Document:

"American National Standard Safety Requirements for the Storage and Handling of Anhydrous Ammonia" (K 61.1-1972). This standard applies to ANSI and The Fertilizer Institute. Both of these Societies work with The Compressed Gas Association through Committee.

The ANSI Guide:

Applies to the design, construction, location, installation and operation of anhydrous ammonia systems. The Standard does not apply to (a) ammonia manufacturing plants, (b) refrigeration plants; or (c) ammonia transportation pipelines.

Additional Information:

"Containers exceeding 36 inches in diameter or 250-gallon capacity shall be stress relieved after fabrication or when fabricated with cold-formed heads. Hot-formed heads do not require a stress relief.

"Welding to the shell, head, or any other part of the container subject to internal pressure shall be done in compliance with the code under which the container was fabricated. Other welding is permitted only on saddle plates, lugs, or brackets attached to the container by the container manufacturer.

"All containers, except refrigerated storage tanks with a design pressure of less than 15 psig and containers constructed in accordance with specifications of the DOT, shall be inspected by a person that has a current certificate of competency from The National Board of Boiler and Pressure Vessel Inspectors.

"Piping used on nonrefrigerated systems shall be at least ASTM A-53 Grade B, electric resistance welded and electric flash welded or equal. Such pipe shall be at least Schedule 40 when joints are welded, or welded and flanged. Such pipe shall be at least Schedule 80 when joints are threaded. Brass, copper, or galvanized steel pipe or tubing shall not be used.

"Cast-iron fittings shall not be used but this shall not prohibit the use of fittings made specifically for ammonia service of malleable or nodular iron such as Specification ASTM A 47 or ASTM A 395.

"After assembly, all piping and tubing shall be tested and proved to be free of leaks at a pressure not less than the normal operating pressure of the system.

"The shell or head thickness of any container shall not be less than 3/16 inches."

5. American Institute of Chemical Engineers (AIChE)

345 East 47th Street, New York, New York 10017. Telephone: (212) 644-7658

J. C. Foreman, Executive Director and Secretary

Monograph:

"Safety in Air and Ammonia Plants." (The Proceedings of The Annual Symposia on Safety in Ammonia Plants -- Fall AIChE meetings held each year.)

Ammonia Plant Safety Series:

T-67	Ammonia Plant Safety, Vol. 21 (1979)
T-63	Ammonia Plant Safety and Related Facilities, Vol. 20 (1978)
T-59	Ammonia Plant Safety and Related Facilities, Vol. 19 (1977)
T-56	Ammonia Plant and Safety, Vol. 18 (1976)
T-52	Ammonia Plant and Safety, Vol. 17 (1975)
T-48	Ammonia Plant and Safety, Vol. 16 (1974)
T-45	Ammonia Plant and Safety, Vol. 15 (1973)
T-42	Ammonia Plant and Safety, Vol. 14 (1972)
T-38	Ammonia Plant and Safety, Vol. 13 (1971)
T-35	Ammonia Plant and Safety, Vol. 12 (1970)
-	Ammonia Plant and Safety, Vol. 11 (1969)

6. Manufacturing Chemists Association

1825 Connecticut Avenue, Washington, DC 20009

Brochure:

Chemical Safety Data. (Not presently available -- under revision.)

7. U. S. Department of Transportation (DOT)

Washington, DC

Code:

Federal Regulations-49-Transportation-Parts 100 to 199, revised as of October 1, 1978

Report:

DOT-F-H-11-8568

Published by the Office of the Federal Register National Archives and Records Service General Services Administration.

Additional Information:

Selected requirements that apply to tanks used for the transportation of ammonia follow:

Specifications -- Steel Grades -- Testing and Inspection

Department of Transportation (DOT) specifications that apply to the container are DOT-51, MC-330, and MC-331.

"Each MC-330 and MC-331 cargo tank used for anhydrous ammonia which is constructed of quenched and tempered (QT) steel or constructed of other than QT steel but without post-weld heat treatment, must be internally inspected by the wet fluorescent magnetic particle method immediately prior to and in conjunction with the performance of any hydrostatic re-test prescribed. The wet fluorescent magnetic particle inspection must be in accordance with Section V of the ASME Code and CGA Technical Bulletin TB-2 titled, 'Guidelines For Inspection and Repair of MC-330 and MC-331 Cargo Tanks,' 1975 edition. (This paragraph does not apply to cargo tanks that do not have manholes.)

"All parts of tanks and appurtenances shall be of steel. Aluminum, copper, silver, zinc, their alloys, and brazed joints shall not be permitted.

"Each MC-330 cargo tank must be equipped with liquid discharge controls that conform to Part 178.337-11cc of this Specification at each liquid discharge opening.

"Each cargo tank must be tested and inspected at least once every five years.

"The tank, less any fittings, must be subjected to a hydrostatic or pneumatic pressure of 1-1/2 times the design pressure (maximum allowable working pressure or related pressure) of the tank.

"A cylinder that leaks, is bulged, has defective valves or safety devices, bears evidence of physical abuse, fire, or heat damage, or detrimental rusting or corrosion, must not be used unless it is properly repaired and re-qualified as prescribed in these regulations.

"Specifications MC-330 and MC-331 cargo tanks constructed of other than quenched and tempered (NQT) steel are authorized for all grades of anhydrous ammonia. Specifications MC-330 and MC-331 cargo tanks constructed of QT steel are authorized for anhydrous ammonia having a minimum water content of 0.2% by weight. Any tank being placed in anhydrous ammonia service or a tank which has been in other service or has been opened for inspection, test or repair, must be cleaned of the previous product and must be purged of air before loading.

"Anhydrous ammonia must not be offered for transportation or transported in Specification MC-330 and MC-331 cargo tanks constructed of QT steel except as follows:

(a) The ammonia must have a minimum water content of 0.2% by weight. Any addition of water must be made using steam condensate, deionized or, distilled water.

(b) Except as otherwise provided in this paragraph, each person offering for transportation or transporting anhydrous ammonia shall perform a periodic analysis for prescribed water content in the ammonia. The analysis must be performed (1) from a sample of the ammonia in storage taken at least once every 7 days, or each time ammonia is added to the storage tanks, whichever is less frequent; or, (2) at the time the cargo tanks are loaded, then a sample of the ammonia taken from at least one loaded cargo tank out of each 10 loads, or from one cargo tank every 24 hours, whichever is less frequent; or, (3) at the same frequency as described above (2) from a sample taken from the loading line to the cargo tank.

(c) If water is added at the time of loading (1) the sample for analysis must be taken from a point in the loading line between the water injection equipment and the cargo tank, and (2) positive provisions must be made to assure water injection equipment is operating.

(d) If water injection equipment becomes inoperative, suitable corrective maintenance must be performed after which a sample from the first loaded cargo tank must be analyzed for prescribed water content.

(e) The analysis method for water content must be as prescribed in CGA Pamphlet G 2.2, titled 'Tentative Standard Method for Determining Minimum of 0.2% Water in Anhydrous Ammonia' 1975 edition.

(f) "Records indicating the results of the analysis taken, as required by this paragraph, must be retained for 2 years and must be open to inspection by representatives of the Department (DOT).

(g) Each person receiving anhydrous ammonia containing 0.2% water by weight may offer for transportation or transport that ammonia without performing the prescribed analysis for water content provided (1) the ammonia received was certified as containing 0.2% water as prescribed in this documents' paragraph 172.203 (h)(1)(i) and 177.817(a) of this document, 'Code Of Regulations-49-Transportation,' and (2) the amount of water in the ammonia has not been reduced by any means.

"Every cargo tank whether constructed in accordance with DOT specifications or being operated as a novel tank under exemption authorization shall not continue in service unless it has successfully fulfilled the testing requirements as set forth in this documents' paragraph 177.824. (Retesting and Inspection of Cargo Tanks.)

"Every cargo tank shall receive an external visual inspection at least once in every 2 year period. The first such inspection shall be required at the time the next hydrostatic re-test is due or prior to January 31, 1969, whichever comes first."

Tank Repair -- Welding -- Heat Treatment

All cracks and other defects found must be repaired in accordance with the repair procedures described in CGA Technical Bulletin TB-2, titled, "Guidelines for Inspection and Repair of MC-330 and MC-331 Cargo Tanks," 1975 edition and section VIII of the edition of the ASME Code under which the tank was built.

"Each tank having cracks and defects requiring welded repairs must meet all of the following requirements:

(a) Meet ASME Code regarding inspection of materials of construction of the tank and its appurtenances as well as for test and inspection of the completed assembly. Tanks constructed in accordance with Part UHT of the ASME Code must use a test pressure at least twice the tank design pressure.

(b) Tanks constructed in accordance with Part UHT of the ASME Code must be subjected after post-weld heat treatment and hydrostatic tests to a wet fluorescent magnetic particle inspection to be made on all welds in or on the tank shell and heads both inside and out. The inspection must conform to Appendix VI of the ASME Code, Paragraphs UA-70 through UA-72, except that permanent magnets shall not be used.

(c) Tanks larger than 3500 gallons (water capacity) other than those described in (b) above unless fully radiographed, shall have all welds in or on the shell and heads both inside and outside tested by either the wet fluorescent magnetic particle method conforming to Appendix VI of the ASME Code, liquid dye penetrant method, or ultrasonic testing in accordance with Appendix U of the ASME Code. Permanent magnets must not be used to perform the magnetic particle inspection.

(d) All defects found shall be repaired and then the tanks again post-weld heat treated, if such heat treatment was previously used, and then the repaired areas retested.

(e) Post-weld heat treatment after minor weld repairs is not required.

(f) When any repairs are made, including those by grinding, the tank must be examined by the wet fluorescent magnetic particle method after hydrotest to assure that all defects have been removed.

A tank used for anhydrous ammonia must be post-weld heat treated. The post-weld heat treatment must be as prescribed in the ASME Code, but in no event at less than 565.6°C (1050°F) tank metal temperature.

Each tank constructed in accordance with Part UHT of the ASME Code must be subjected, after post-weld heat treatment and hydrostatic tests, to a wet fluorescent magnetic particle inspection to be made on all welds in or on the tank shell and heads both inside and outside. The method of inspection must conform to Appendix VI of the ASME Code, paragraph UA-70 through UA-72 except that permanent magnets shall not be used.

On tanks of over 3500-gal water capacity, other than those described in the previous paragraph, unless fully radiographed, a test must be made of all welds in or on the shell and heads both inside and outside by either the wet fluorescent magnetic particle method conforming to Appendix VI of the ASME Code, liquid dye penetrant method, or ultrasonics testing in accordance with Appendix U of the ASME Code. Permanent magnets must not be used to perform the magnetic particle inspection. All defects found shall be repaired, the tanks shall then again be post-weld heat treated, if such heat treatment was previously performed, and the repaired areas shall again be tested.

When fabrication is done in accordance with Part UHT of the ASME Code, filler material containing more than 0.08% vanadium must not be used." (See DOT Specification 178.337-4 Joints.)

8. U. S. Coast Guard, Department of Transportation

U. S. Coast Guard, Washington, DC 20590. Telephone: (202) 426-2559

Lt. Cmdr. Tom Jenkins, U. S. Coast Guard Headquarters
Joseph J. Jakabcin, G-MHM-3

Reference Regulations:

DOT, C.G.-257-1, Sept. 1977-"Rules and Regulations for Cargo and Miscellaneous Vessels"

DOT, C.G.-Title 46-Shipping, Chapter 1, Subparts, 56.60 to 56.97-40, 98.25, 150.50-30, 151.04-5c and 151.50-32

DOT, C.G.-49 CFR Sections 173.315 Table Note 12 and 173.33 G-1

Additional Information:

Selected regulations pertaining to ammonia follow:

(a) "Copper, copper alloys and copper-bearing alloys shall not be used as materials of construction for tanks, pipelines, valves, fittings, and other items of equipment that may come in contact with anhydrous ammonia, liquid or vapor.

(b) Non-ferrous materials such as copper, copper alloys, and aluminum alloys shall not be used as materials of construction for valves, fittings or accessory equipment that may come into contact with anhydrous ammonia, liquid or vapor.

(c) The low melting points of aluminum and aluminum alloys must be recognized. These materials shall not be used to conduct flammable, combustible or dangerous* fluids or for vital systems unless authorized by the Commandant.

(d) Each cargo tank shall be subjected to internal examination at least once in each 8 calendar years, to the extent and if deemed necessary by the marine inspector.

(e) To the extent he deems it necessary, the Officer In Charge, Marine Inspection, may require that sufficient insulation shall be removed from insulated tanks at least once each 8 calendar years to permit spot external examination of the tanks and insulation in accordance with paragraph 151.04-5c.

(f) If tanks are required to be stress-relieved, no appendages shall be welded to the tanks after they have been stress-relieved unless authorized by the Commandant.

(g) All valves, flanges, fittings and accessory equipment shall be of a type suitable for use with anhydrous ammonia and shall be made of steel, or malleable or nodular iron meeting the requirements of 56.60-1 of Sub Chapter F (Marine Engineering)(Chapter 1, Title 46-Shipping--C.G. Regulation). Valves shall be fitted with non-corrosive material suitable for ammonia service.

(h) Valves, flanges and pipe fittings shall be of the tongue and groove or raised-face type, fitted with suitable gasket material. Welded fittings shall be used wherever possible and the number of pipe joints shall be held to a minimum. Threaded joints are not permitted for pipe diameters exceeding two inches. Brazed joints are prohibited.

*For definition of flammable or combustible fluids see Para. 30.1-22 and 30.10-15 of Sub Chapter D (Tank Vessels) of Chap. 1, Title 46-Shipping, USCG. Dangerous fluids are those covered by regulations in Part 98 of Sub Chapter 1 (Cargo and Misc. Vessels, Chap. 1).

(i) Piping shall be of seamless steel meeting the requirements of 56.60-1, of Sub Chapter F (Marine Engineering) (USCG Title 46-Shipping, Chapter 1). The piping shall be of not less than Schedule 40 thickness. All ammonia piping must meet the requirements of the new LNG tanker standard 46 CFR, Parts 31, 34, 54, 98 and 154 that was placed into law on May 3, 1979.

(j) All piping weldments shall be post-weld heat treated for stress-relief in accordance with the procedure of Sub Part 56.85 (USCG, Title 46-Shipping, Chapter 1).

(k) The requirements of paragraph 151.50-30 for compressed gases are also applicable to the shipment of anhydrous ammonia."

9. American Society of Mechanical Engineers (ASME)

345 East 47th Street, New York, New York 10017. Telephone: (212) 752-6800

Mr. O. L. Lewis, President

Reference:

None presently available; being reprinted

B. Associations without Existing Specifications for Ammonia

1. American Iron and Steel Institute (AISI)

1000 16th Street, N.W., Washington, DC 20036. Telephone: (202) 452-7100

2. American Petroleum Institute (API)

2101 L Street, N.W., Washington, DC. Telephone: (202) 457-7266

3. National Association of Corrosion Engineers (NACE)

P.O. Box 986, Katy, Texas 77450. Telephone: (713) 492-0535

Mr. Jim Dillard, Technical Activity Director

NACE, Committee T-5E did not publish a report on ammonia while the Committee was active. The Committee did prepare a report in cooperation with ASTM Committee A-10 entitled "SCC of Austenitic Chromium-Nickel Stainless Steels" (1960). The report is only available from ASTM.

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